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PROVISION OF QUALITY AND POWER OF INCENTIVE SCHEMES IN REGULATED INDUSTRIES

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by

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and

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Abstract

We study the incentives of a regulated monopoly to supply quality. For an experience good, the current level of sales yields no information about quality and the cost reimbursement rule is the only instrument to achieve the conflicting goals of provision of quality and cost reduction. A high concern for quality moves optimal contracts toward cost-plus contracts; and an increase in the discount factor raises the power of incentive schemes. In contrast, for a search good, direct sales incentives can be provided to supply quality; whether a high quality concern drives optimal contracts toward cost-plus or fixed-price contracts then depends on whether quantity and quality are net substitutes or net complements.

1. Introduction.

An unregulated monopolist may have two incentives to provide quality: the "sales incentive" and the "reputation incentive." When quality is observed by consumers before purchasing (search good), a reduction in quality reduces sales, and thus revenue as the monopoly price exceeds marginal cost. In contrast, when quality is observed by consumers only after purchasing (experience good), the monopolist has no incentive to supply quality unless consumers may repeat their purchase in the future. The provision of quality is then linked with the monopolist's desire to keep its reputation and preserve future profits.

In this paper, we investigate whether similar incentives to provide quality exist in a regulated environment. Before doing so, it is useful to distinguish between <u>observable</u> and <u>verifiable</u> quality. Quality is usually observable by consumers either before or after consumption. Quality is furthermore verifiable if its level can be (costlessly) described *ex-ante* in a contract and ascertained *ex-post* by a court. When quality is verifiable, the regulator can impose a quality target to the regulated firm or more generally reward or punish the firm directly as a function of the level of quality. For instance a regulatory commission may dictate the heating value of gas or may punish an electric utility on the basis of the number and intensity of outages. Formally, the regulation of verifiable quality is analogous to the regulation of a multiproduct firm, as the level of quality on a given product may be treated as the quantity of another, fictitious product.[1]

This paper will be concerned with observable but <u>unverifiable</u> quality. The effectiveness of a new weapons system, the quality of broadcasting by a regulated television station, the level of services enjoyed by a railroad

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[1] See Sappington [1983] and Laffont-Tirole [1988] for information-based theories of the regulation of a multiproduct firm with and without cost regulation.

passenger or the probability of a core melt-down at a nuclear plant are hard to quantify and include in a formal contract. As Kahn [1988, p. 22] argues:

> But it is far more true of quality of service than of price that the primary responsibility remains with the supplying company instead of with the regulatory agency, and that the agencies, in turn, have devoted much more attention to the latter than to the former. The reasons for this are fairly clear. Service standards are often much more difficult to specify by the promulgation of rules.

When quality is unverifiable, the regulator must recreate the incentives of an unregulated firm to provide quality without throwing away the benefits of regulation. First, it must reward the regulated firm on the basis of sales. Second, the threat of nonrenewal of the regulatory license, of second sourcing or of deregulation makes the regulated firm concerned about its reputation as supplier of quality.

The focus of our analysis is the relationship between quality concern and power of optimal incentive schemes. An incentive scheme is high- (low-) powered if the firm bears a high (low) fraction of its realized costs. Thus a fixed-price contract is very high-powered, and a cost-plus contract is very low-powered.

The link between quality and the power of incentive schemes has been much discussed. For instance, there has been a concern that "incentive regulation" (understand: high-powered incentive schemes) conflicts with the safe operation of nuclear power plants by forcing management to hurry work, take shortcuts and delay safety investments. There have been accounts that the switch to a high-powered incentive scheme for British Telecom (price caps) after its privatization produced a poor record on the quality front (Vickers-Yarrow [1988, p. 228]).[2] Similarly, Kahn [1988, I, p. 24] contends

[2] It is not surprising that the dissatisfaction with the quality performance subsequently led to the costly development and monitoring of quality indices to be included in the incentive schemes.

that, under cost-of-service regulation (a very low-powered incentive scheme), in the matter of quality "far more than in the matter of price, the interest of the monopolist on the one hand and the consumer on the other are more nearly coincident than in conflict." Kahn's intuition is that the regulated monopolist does not suffer from incurring monetary costs to enhance quality because these costs are paid by consumers through direct charges. This intuition is incomplete. First, some components of quality involve non monetary costs. Second, and more importantly, under pure cost-of-service regulation, the regulated firm does not gain from providing costly services either so that a low perceived cost of supplying quality does not imply a high incentive to supply quality.[3] Last, in the context of military procurement, Scherer [1964, pp. 165-166] has suggested that

> There is reason to believe that the use of fixed-price contracts would not greatly reduce the emphasis placed on quality in weapons development projects, although it might affect certain marginal tradeoff decisions with only a minor expected impact on future sales.

To give formal arguments to assess the relevance of these perceptions, we introduce two related natural monopoly models of an experience and of a search good. Whether the power of regulatory contracts decreases when quality becomes more desirable depends crucially on whether contractual incentives can be based on sales (on top of cost) or not, i.e., on whether the regulated firm

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[3] In practice, one does not observe pure cost-of-service regulation. Due to the regulatory lag, the regulated firm is, like an unregulated monopolist, the residual claimant for the revenue it generates and costs it incurs between rate reviews (the differences being that the prices are fixed and that the regulated monopolist is concerned about the ratchet effect); thus actual cost-of-service incentive schemes are not as low-powered as one might believe. We will not try to study (variants of) cost-of-service regulation, but will rather focus on optimal regulation.

See Joskow and Rose [1987] for empirical evidence on the level of services under cost-of-service regulation.

supplies a search or an experience good. In our two-period model of an experience good, the regulator purchases a fixed amount from the regulated firm. Because quality is *ex-ante* unverifiable, the regulator has no alternative than to accept the product. The supplier's incentive to provide quality is then the reputation incentive, i.e., the possibility of losing future sales. In contrast, our static search good model has the firm sell to consumers who observe quality before purchasing. The former model is best thought of as a procurement model, and the latter as a regulation model, although other interpretations are possible (in particular, some regulated products are experience goods).

To separate issues in this paper we choose cost functions for which the incentive-pricing dichotomy (Laffont-Tirole [1988]) holds. Pricing is not used to extract the rent due to asymmetric information.

In the case of an experience good, we argue that incentives to supply quality and those to reduce cost are inherently in conflict. The regulator has a single instrument -- the cost reimbursement rule -- to provide both types of incentives. High-powered incentives schemes induce cost reduction but increase the firm's perceived cost of providing quality. This crowding-out effect implies that the more important quality is, the lower the power of an optimal incentive scheme. We also show that when the firm becomes more concerned about the future, its perceived cost of supplying quality decreases, which induces the regulator to offer more powerful incentive schemes. We thus find Scherer's suggestion quite perceptive.

In the case of a search good, the crowding-out effect is latent but has no influence on the power of incentive schemes. In our model, the regulator can separate the two incentive problems because it has two instruments: cost reimbursement rule and sales incentives. The incentive to provide quality is provided through a reward based on a quality index, which is the level of sales corrected by the price charged by the firm. As in the case of an

experience good, the cost-reducing activity is encouraged through the cost reimbursement rule, which is now freed from the concern of providing the right quality incentives. This dichotomy does not, however, imply that an increase in the desirability of quality has no effect on the power of incentive schemes; it has an indirect effect because higher services may increase or decrease the optimal level of output, which in turn changes the value of reducing marginal cost and thus affects the regulator's arbitrage between incentives and rent extraction.

While there exists a vast literature on the provision of quality by an unregulated monopoly,[4] surprisingly little theoretical research has been devoted to this issue in a regulated environment. Besanko *et al.* [1987] assume that the monopolist offers a range of verifiable qualities to discriminate among consumers with different tastes for quality (à la Mussa-Rosen [1978]) and investigate the effect of imposing minimum quality standards or price ceilings (see also Laffont [1987]). Closer to our paper is the work of Lewis and Sappington [1988], who examine both verifiable and unverifiable quality. Sales depend on a demand parameter, price and quality. When quality is unverifiable, Lewis and Sappington assume that the regulator monitors prices (but not cost, quantity or quality) and operates transfers to the firm. To give incentives to provide quality the regulator allows prices in excess of the (known) marginal cost. A higher mark-up above marginal cost raises the dead-weight loss due to pricing but also raises quality. Lewis and Sappington show that the rent derived by the firm from its private information about the demand parameter is higher when quality is verifiable than when it is not. Our work differs from theirs in that, among other things, we allow cost observation and focus on the effect of quality concerns on the power of incentive schemes.

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[4] See, e.g., Tirole [1988, chapters 2 and 3].

The paper is organized as follows. Section 2 develops a single product, static model of sales incentive. The regulator observes the total cost, price and output of a natural monopoly. His imperfect knowledge of the production technology and of the demand function makes the problems of inducing cost-reducing activities and provision of quality/services non trivial. Services are monetary or nonmonetary; monetary services enter total cost but cannot be disentangled from other costs, i.e., cannot be recovered from the aggregate accounting data. Section 3 solves for the optimal incentive scheme. Section 4 shows that the optimum can be implemented by a scheme that is linear in both realized cost and a quality index that is computed from price and sales data. Section 5 links variations in the quality concern and the slope (power) of incentive schemes. Section 6 discusses reputation incentives. It develops a model of an experience good in which a quality choice has permanent effects. The observation of quality today reveals information about future quality. This model is one of moral hazard (unverifiable intertemporal choice of quality). In contrast, many models of reputation in the industrial organization literature have assumed that the firm can be "born" a high- or low-quality producer, and can, at a cost masquerade as a high-quality producer if it is a low-quality producer. Appendix B stages a variant of the reputation models of Kreps-Wilson [1982], Milgrom-Roberts [1982] and Holmström [1982] in a regulatory context and obtains results similar to those in the moral-hazard model. Section 7 concludes the paper and suggests some desirable extensions.

Part A: Search goods.

2. The model.

We consider a natural monopoly producing a single commodity in quantity q with observable but unverifiable quality/services s. Before describing the model, we briefly discuss the methodology. We assume that the firm's cost

increases with output and with the level of services, decreases with the cost reducing activity e and depend on some privately known technological parameter β: $C = C(q,s,e,\beta)$. On the demand side, we assume that the regulator does not perfectly know the demand curve; otherwise he would be able to infer the exact level of services provided by the firm from the price and output data; we thus posit an inverse demand function $p = P(q,s,\theta)$, where P decreases with q and increases with s, and θ is a demand parameter which is known by the firm only.[5] Our model is thus one of two-dimensional moral hazard (e and s) and especially two-dimensional adverse selection (β and θ). In order to obtain a closed form solution, we specialize it to <u>linear</u> cost and demand functions, which enable us to reduce the problem to a one-dimensional adverse selection one.

Quantity and quality are said to be <u>gross complements</u> if an increase in quality raises the consumers' marginal willingness to pay: $\frac{\partial^2 S^g}{\partial s \partial q} = \frac{\partial p}{\partial s} > 0$. Quantity and quality are <u>net complements</u> if an increase in quality raises the net marginal willingness to pay, i.e., the difference between price and marginal cost: $\frac{\partial^2 (S^g - C)}{\partial s \partial q} = \frac{\partial (p - C_q)}{\partial s} > 0$. As we will see, the effect of quality concerns on the power of incentive schemes depends on whether quantity and quality are net complements or net substitutes.

Let us now describe the model in more detail.

The (variable) cost function is

$$(2.1) \qquad C = (\beta + s - e)q,$$

where β in $[\underline{\beta},\bar{\beta}]$ is an intrinsic cost parameter known only to the firm and e is the firm's cost-reducing activity or effort and is also unobservable by the regulator. Note that (2.1) assumes that the cost of providing quality is

[5] See Sappington [1983] and Laffont-Tirole [1988] for information-based theories of the regulation of a multiproduct firm with and without cost regulation.

monetary. The remark below shows that a relabelling of variables allows the cost of providing quality to be nonmonetary.

The cost C is verifiable and, by accounting convention, born by the regulator. Similarly, we assume without loss of generality that the regulator receives directly the payment pq made by the consumers in exchange for the good, where p is the good's price. After paying C and receiving pq, the regulator pays a net transfer t to the firm (that will depend on observable and verifiable variables C,p,q).

Letting $\psi(e)$ (with $\psi' > 0$, $\psi'' > 0$, $\psi''' \geq 0$)[6] denote the firm's disutility of effort, the firm's utility or rent is

$$(2.2) \qquad U = t-\psi(e).$$

Consumers observe the quality before purchasing the (search) good and derive from the consumption of the commodity a gross surplus:

$$(2.3) \qquad S^g(q,s,\theta) = (A+ks-h\theta)q - \frac{B}{2}q^2 - \frac{(ks-h\theta)^2}{2},$$

where A,B,h,k are known positive constants and θ in $[\underline{\theta},\bar{\theta}]$ is a demand parameter.[7]

The inverse demand curve is then

$$(2.4) \qquad p = \frac{\partial S^g}{\partial q} = A+ks-h\theta-Bq.$$

Quantity and quality are always gross complements in this model, and are net complements if $k > 1$ and net substitutes if $k < 1$. We will of course focus on

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[6]The technical assumption $\psi''' \geq 0$ ensures that stochastic mechanisms are not optimal.

[7]Note that S^g differs from 0 at $q = 0$. One can think of S^g as a local approximation in the relevant range. Or one might allow services to affect consumers even in the absence of consumption. The reader should be aware that the Spencian comparison between the marginal willingnesses to pay for quality of the marginal and the average consumers under unregulated monopoly requires that S^g be equal to zero at $q = 0$.

parameters that put the problem in the relevant range $\left(\frac{\partial S^g}{\partial q} > 0, \frac{\partial S^g}{\partial s} > 0\right)$.

Let $1+\lambda > 1$ be the social cost of public funds.[8] The consumers'/taxpayers' net surplus is:

$$(2.5) \qquad S^n = (A+ks-h\theta)q - \frac{B}{2}q^2 - \frac{(ks-h\theta)^2}{2} - pq - (1+\lambda)(C-pq+t).$$

(2.5) includes the taxes needed by the regulator to finance the firm. From (2.4), (2.5) can be rewritten:

$$(2.6) \qquad S^n = (A+ks-h\theta)q - \frac{B}{2}q^2 - \frac{(ks-h\theta)^2}{2} + \lambda(A+ks-h\theta-Bq)q - (1+\lambda)(C+t).$$

<u>Remark</u>: As mentioned above, our model covers the case of a nonmonetary cost of providing quality. Suppose that the accounting cost is $C = (\beta-\tilde{e})q$, where $\tilde{e}$ is the effort to reduce cost. Suppose further that the firm exerts a second type of effort s that provides services to consumers s per unit of output. Then the disutility of effort is $\psi(\tilde{e}+s)$. Letting $e = \tilde{e}+s$, the accounting cost becomes $C = (\beta+s-e)q$ and the disutility of effort is $\psi(e)$. This remark shows vividly that cost-reducing activities ($\tilde{e}$) and the provision of services (s) are <u>substitute</u>: an increase in services raises the marginal disutility $\psi'(\tilde{e}+s)$ of exerting effort to reduce cost.

■ Under <u>complete information</u>, a utilitarian regulator maximizes the sum of consumer and producer surpluses under the constraint that the firm be willing to participate:

$$(2.7) \qquad \max_{\{q,s,e\}} \Big\{ W = (1+\lambda)(A+ks-h\theta)q - B(\frac{1}{2}+\lambda)q^2 - \frac{(ks-h\theta)^2}{2}$$

$$- (1+\lambda)((\beta+s-e)q+t)+t-\psi(e)\Big\},$$

s.t.

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[8] λ is strictly positive because distortive taxes are used to raise public funds.

$$(2.8) \qquad t-\psi(e) \geq 0,$$

where (2.8) normalizes the firm's reservation utility to be zero. For B large enough, the program {(2.7),(2.8)} is concave and its (interior) maximum is characterized by the first-order conditions:

$$(2.9) \qquad (1+\lambda)p-\lambda Bq = (1+\lambda)(\beta+s-e)$$

$$(2.10) \qquad (1+\lambda)kq-k(ks-h\theta) = (1+\lambda)q$$

$$(2.11) \qquad \psi'(e) = q$$

$$(2.12) \qquad t = \psi(e).$$

(2.9) equates the marginal social utility of the commodity (composed of the marginal utility of the commodity to consumers S_q^n and the financial marginal gain $\frac{d}{dq}(\lambda pq)$ to its marginal social cost $((1+\lambda)C_q)$. Similarly, (2.10) equates the marginal social utility of service quality to its marginal social cost. (2.11) equates the marginal disutility of effort $\psi'(e)$ to its marginal utility q. And (2.12) says that no rent is left to the firm.

Equations (2.9) and (2.10) are most easily interpreted in the following forms:

$$(2.9') \qquad \frac{p-C_q}{p} = \frac{\lambda}{1+\lambda}\frac{1}{\eta} \qquad \text{where } \eta = \frac{p}{Bq}$$

$$(2.10') \qquad \frac{\partial S^g}{\partial s} + \lambda \frac{\partial p}{\partial s} q = (1+\lambda) \frac{\partial C}{\partial s}.$$

The Lerner index -- or price-marginal cost ratio -- is equal to a Ramsey index (a number between 0 and 1 times) the inverse of the elasticity of demand. And the optimal level of services equates the marginal gross surplus plus the shadow cost of public funds times the increase in revenue to the social marginal cost of quality.

For the record, it is worth comparing the regulated level of quality with that chosen by an unregulated monopoly. Because the cost and demand functions are linear in services, the monopoly solution is "bang-bang." Quality is either zero if quantity and quality are net substitutes or maximal (if an upper bound on quality exists) if quantity and quality are net complements. As in Spence [1975], an unregulated monopolist may over- or undersupply quality for a given quantity.

3. Optimal regulation under asymmetric information.

We now assume that the regulator faces a multidimensional asymmetry of information. He knows neither β nor θ and cannot observe e and s. However, he observes C, p and q. Faced with this informational gap, the regulator is assumed to behave as a Bayesian statistician who maximizes expected social welfare and has a prior distribution F_1 on $\beta \in [\underline{\beta},\bar{\beta}]$ and a prior distribution F_2 on $\theta \in [\underline{\theta},\bar{\theta}]$. The firm knows β and θ before contracting.

The regulator knows that consumers equate their marginal utility of the commodity to the price, hence:

$$p = A+ks-h\theta-Bq. \tag{3.1}$$

Using the observability of p and q, it is possible to eliminate the unobservable service quality level s in the consumers' gross valuation of the commodity which becomes:

$$S^g(p,q) = \frac{B}{2}q^2+pq - \frac{1}{2}(p-A+Bq)^2. \tag{3.2}$$

Similarly, the cost function becomes:

$$C = (\beta + \frac{h\theta}{k} -e)q + q\left(\frac{p-A+Bq}{k}\right). \tag{3.3}$$

Note that β and θ enter the cost function only through the linear combination $\gamma = \beta + \frac{h}{k}\theta$. This feature which also holds for the firm's and

regulator's objective functions (see below) reduces the model to a single-dimensional adverse-selection problem, and will enable us to obtain a closed-form solution.[9]

Consider now the firm's objective function (recalling our accounting convention that the regulator pays the cost and receives the revenue):

$$(3.4) \qquad U = t-\psi(e) = t-\psi\left[\gamma + \frac{p-A+Bq}{k} - \frac{C}{q}\right].$$

From the revelation principle we can restrict the problem of control of the firm to the analysis of direct and truthful revelation mechanisms.

For simplicity[10] we assume that the cumulative distribution function $F(\cdot)$ of γ on $[\underline{\gamma},\bar{\gamma}] = \left[\underline{\beta} + \frac{h}{k}\,\underline{\theta}, \bar{\beta} + \frac{h}{k}\,\bar{\theta}\right]$ (the convolution of F_1 and F_2) satisfies the monotone hazard rate property: $\frac{d(F(\gamma)/f(\gamma))}{d\gamma} > 0$. Appendix A.1 derives sufficient conditions on the primitive distributions F_1 and F_2 for this to hold.

The first- and second-order conditions of incentive compatibility are (see Appendix A.2):

$$(3.5) \qquad \dot{t} = \left[\frac{\dot{p}+B\dot{q}}{k} - \dot{\left(\frac{C}{q}\right)}\right]\psi'$$

$$(3.6) \qquad \frac{\dot{p}+B\dot{q}}{k} - \dot{\left(\frac{C}{q}\right)} \leq 0$$

where $\dot{t} \equiv dt/d\gamma$, etc...

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[9] A more general formulation of the consumers' tastes would lead to a truly two-dimensional adverse-selection problem. The qualitative results would be similar, but the technical analysis would be greatly complicated (See Laffont, Maskin and Rochet [1987], for example).

[10] This assumption avoids bunching without significant loss for the economics of the problem.

The social welfare function can be written (see (2.7)):

$$(3.7)\qquad W = \frac{B}{2}q^2 + (1+\lambda)pq - \frac{1}{2}(p-A+Bq)^2 - (1+\lambda)\left((\gamma-e)q+q\left[\frac{p-A+Bq}{k}\right]+\psi(e)\right)-\lambda U.$$

The regulator maximizes the expected social welfare function under the incentive compatibility conditions {(3.5),(3.6)} and the individual rationality constraint of the firm:

$$(3.8)\qquad U(\gamma) \geq 0 \qquad \text{for any } \gamma.$$[11]

The maximization program is, using U as a state variable,

$$(3.9)\qquad \text{Max} \int_{\underline{\gamma}}^{\bar{\gamma}} \left\{\frac{B}{2}q^2+(1+\lambda)pq-\frac{1}{2}(p-A+Bq)^2-(1+\lambda)\left[(\gamma-e)q+q\left[\frac{p-A+Bq}{k}\right]+\psi(e)\right]-\lambda U\right\}dF(\gamma)$$

s.t.

$$(3.10)\qquad \dot{U}(\gamma) = -\psi'(e)$$

$$(3.11)\qquad \dot{e}-1 \leq 0$$

$$(3.12)\qquad U(\bar{\gamma}) \geq 0.$$

Equation (3.10) is another version of the first-order incentive compatibility constraint (3.5). Moreover, because $U(\gamma)$ is decreasing, the IR-constraint (3.8) reduces to the boundary condition (3.12). From Appendix A.2, (3.11) is a rewriting of the second-order condition (3.6). We ignore it in a first step and later check that it is indeed satisfied by the solution of the subconstrained program. For A and B large enough, the program is concave and the optimum is characterized by its first-order conditions (see Appendix A.3). Let $\mu(\gamma)$ denote the Pontryagin multiplier associated with (3.10) and H the Hamiltonian associated with the program {(3.9), (3.10), (3.12)}. From the Pontryagin principle, we have:

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[11] We implicitly assume here that it is worth producing for any γ in $[\underline{\gamma},\bar{\gamma}]$.

$$(3.13) \qquad \dot{\mu}(\gamma) = -\frac{\partial H}{\partial U} = \lambda.$$

From the transversality condition and (3.13) we derive:

$$(3.14) \qquad \mu(\gamma) = \lambda F(\gamma).$$

Maximizing the Hamiltonian with respect to q, p, e, we get after some algebraic manipulations:

$$(3.15) \qquad (1+\lambda)p - \lambda Bq = (1+\lambda)\left[\gamma - e + \frac{p-A+Bq}{k}\right]$$

$$(3.16) \qquad (1+\lambda)kq - k(p-A+Bq) = (1+\lambda)q$$

$$(3.17) \qquad \psi'(e) = q - \frac{\lambda}{1+\lambda}\frac{F(\gamma)}{f(\gamma)}\psi''(e).$$

Equations (3.15) and (3.16) which correspond to the maximizations with respect to q and p coincide with (2.9) and (2.10). That is, for a given effort e, the price, quantity and quality are the same as under complete information about the technology and demand parameter. This result is reminiscent of (although not implied by) the incentives-pricing dichotomy result for multiproduct firms obtained in Laffont-Tirole [1988]. Appendix A.4 derives a more general class of cost functions for which the dichotomy holds in this quality problem.

To extract part of the firm's rent, the effort is distorted downward for a given output level (compare (3.17) and (2.11)), except when $\gamma = \underline{\gamma}$.

Appendix A.3 shows that for the solution to {(3.15), (3.16), (3.17)}, $\dot{p}(\gamma) > 0$, $\dot{q}(\gamma) < 0$ and $\dot{e}(\gamma) < 0$. In particular the neglected second-order condition for the firm $(1-\dot{e}(\gamma) \geq 0)$ is satisfied.

Next we compare the levels of quality under complete and incomplete information about β and θ:

Proposition 1: The level of quality is lower under incomplete information than under complete information if and only if quantity and quality are net complements.

Proof: See Appendix A.5.

Incomplete information makes rent extraction difficult and reduces the power of incentive schemes, i.e., leads to a decrease in effort. This raises marginal cost and reduces output. If quantity and quality are net complements, lower services are desirable; and conversely for net substitutes. Note that asymmetric information lowers quality exactly when the unregulated monopolist oversupplies quality.

To conclude this section, for a search good sales are an indicator of quality in the same way cost is an indicator of effort (and quality). The regulation of quality and effort under asymmetric information is therefore in the spirit of the regulation of a multi-product firm (see Laffont-Tirole [1988]).

4. Implementation of the optimal regulatory mechanism.

For each announcement of the firm's technological parameter and of the consumers' taste parameter, the regulator imposes a level of average cost to achieve, a quantity to produce and a market price to charge. An appropriate net transfer $t(\gamma)$ is offered to induce truthful behavior.

This transfer can be reinterpreted as follows. Let $z = \frac{C}{q} - \frac{(p-A+Bq)}{k}$. Then, the first-order incentive compatibility condition is (see Appendix A.2):

$$\frac{dt}{d\gamma} + \psi'(\gamma-z)\frac{dz}{d\gamma} = 0 \tag{4.1}$$

or

$$(4.2) \qquad \frac{dt}{dz} = -\psi'(\gamma-z) < 0$$

Differentiating (4.2) we obtain:

$$(4.3) \qquad \frac{d^2t}{dz^2} = -\psi''(\gamma-z)\left[\frac{1}{\frac{dz}{d\gamma}} - 1\right].$$

From the second-order condition $\frac{dz}{d\gamma} \geq 0$ and $1 - \frac{dz}{d\gamma} = \frac{de}{d\gamma} < 0$ from Appendix A.3. Therefore $\frac{d^2t}{dz^2} > 0$, i.e., the transfer as a function of z is a convex and decreasing function (see Figure 1).

FIGURE 1 HERE.

As in Laffont and Tirole [1986], the convex non-linear transfer function t(z) can be replaced by a menu of linear contracts

$$t(z,\gamma) = a(\gamma)+b(\gamma)(z(\gamma)-z),$$

where $z(\gamma)$ is the announced value of $\frac{C}{q} - \frac{(p-A+Bq)}{k}$ and z is the observed *ex-post* value. The transfer is therefore a function of a performance index which subtracts from the realized average cost an approximation of the service quality inferred from market data. In other words, the firm is offered a choice in a menu of linear contracts and is rewarded or penalized according to deviations from an index aggregating cost data and service quality data inferred by the observation of the market price and quantity and the *a priori* knowledge on the demand function.

The coefficient $b(\gamma)$ sharing the overrun in the performance index is $\psi'(e^*(\gamma))$ where $e^*(\gamma)$ is the solution of the regulator's optimization program. Indeed,

$$\underset{(e,\tilde{\gamma})}{\text{Max}} \left\{a(\tilde{\gamma})+\psi'(e^*(\tilde{\gamma}))(z(\tilde{\gamma})-\gamma+e)-\psi(e)\right\}$$

implies $\psi'(e^*(\tilde{\gamma})) = \psi'(e)$ and therefore $e = e^*(\tilde{\gamma})$ and $\dot{a}(\tilde{\gamma})+\psi''\dot{e}^*(\tilde{\gamma})(z(\tilde{\gamma})-z)$

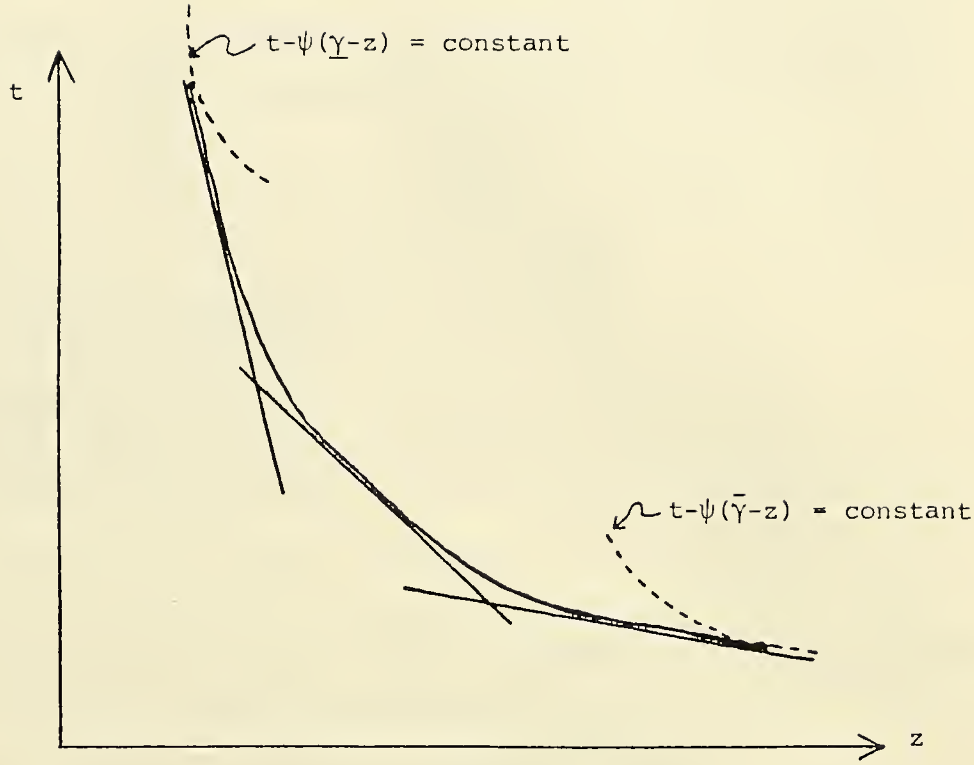

FIGURE 1

$+\psi'(e^*(\tilde{\gamma}))\dot{z}(\tilde{\gamma}) = 0$. If $a(\cdot)$ is chosen so that $\dot{a}(\gamma)+\psi'(e^*(\gamma))\dot{z}(\gamma) = 0$ for any γ or $\dot{a}(\gamma) = \dot{t}(\gamma)$, then $\tilde{\gamma} = \gamma$.

Alternatively, the menu of linear contracts can be decomposed into a linear sharing of total costs overruns with a coefficient $b_1(\gamma) = \dfrac{\psi'(e^*(\gamma))}{q^*(\gamma)}$ and a linear sharing of overruns in the service quality index with a coefficient $b_2(\gamma) = \psi'(e^*(\gamma))$ or

$$t = a(\gamma) + b_1(\gamma)(C(\gamma)-C)+b_2(\gamma)\left[\frac{p(\gamma)+Bq(\gamma)}{k} - \frac{p+Bq}{k}\right].$$

Since the firm is risk neutral we see that our analysis extends immediately to the case in which random additive disturbances affect total cost C and the inverse demand function P.

<u>Proposition 2</u>. The optimal regulatory scheme can be implemented through a menu of contracts that are linear in realized cost and in a quality index equal to sales corrected by the price level:

$$t = \tilde{a}-b_1C+b_2\frac{(p+Bq)}{k} .$$

Clearly, the parameters characterizing the power of the incentive schemes, $b_1(\gamma) = \dfrac{\psi'(e(\gamma))}{q(\gamma)}$ and $b_2(\gamma) = q(\gamma)b_1(\gamma)$, are related. If we study the comparative statics of these coefficients with respect to a parameter x we have

$$\frac{d}{dx}\left[\frac{\psi'(e)}{q}\right] = \frac{\psi''\dot{e}_x q-\psi'\dot{q}_x}{q^2}$$

From $\psi'(e) = q - \frac{\lambda}{1+\lambda}\frac{F}{f}\psi''(e)$, $\dot{q}_x = (\psi'' + \frac{\lambda}{1+\lambda}\frac{F}{f}\psi''')\dot{e}_x$ and

$$\frac{d}{dx}\left[\frac{\psi'(e)}{q}\right] = \dot{e}_x\,\frac{\lambda}{1+\lambda}\,\frac{F}{f}\,[\psi''^2-\psi'\psi'''].$$

The comparative statics of $b_2(\gamma) = \psi'(e^*(\gamma))$ is the same as the

comparative statics of $e^{*}(\gamma)$ and the comparative statics of $b_1(\gamma)$ is identical as long as ψ''' is not too large, which we will assume in Section 5 (of course, no such assumption is needed if one studies the slope of the incentive schemes with respect to marginal cost). Note that b_1 and b_2 are then positively correlated over the sample of types.

5. Concern for quality and the power of incentive schemes.

This section studies the effects of an increase in the consumers' marginal surplus from quality ($\partial S^g/\partial s$) and of an increase in the marginal cost of supplying quality ($\partial C/\partial s$) on the power of incentive schemes. For a clean analysis of these effects, the change must not affect the structure of information, in particular the information revealed by the demand data about the level of quality or by the cost data about cost-reducing effort. The three changes we consider yield identical results (their proofs are provided in Appendix A6):

■ Suppose first that the consumers' gross surplus S^g is replaced by $\tilde{S}^g = S^g + \ell(ks - h\theta, \nu)$ where $\ell_{11} < 0$ and $\ell_{12} > 0$ (ν is a parameter indexing the marginal gross surplus with respect to quality).[12] Note that a change in ν does not affect the inverse demand curve and therefore does not change the information revealed by q and p about s. The first-order conditions (3.15) to (3.17) are unchanged except that $\left\{\frac{\partial \ell}{\partial s}\left[B - \frac{1+\lambda}{k}\right]\right\}$ and $\left\{\frac{\partial \ell}{\partial s}\,\frac{1}{k}\right\}$ must be added to (3.15) and (3.16) respectively. Differentiating (3.15) to (3.17) totally with respect to ν yields:

[12] Subscripts here denote partial derivatives.

Proposition 3: An increase in the concern for quality (in the sense of an increase in ν) raises the power of incentive schemes if quantity and quality are net complements and lowers the power of incentive schemes if they are net substitutes.

■ Next let us consider an increase in the marginal cost of quality. To keep the structure of information constant, we transform the cost function into $\tilde{C} = C+m(ks-h\theta,\rho)$ where $m_{11} > 0$ and $m_{12} > 0$ (an increase in ρ corresponds to an increase in marginal cost. The structure of information is kept unchanged because the term $ks-h\theta$ is equal to $p-A+Bq$ and is therefore verifiable).

Proposition 4: An increase in the marginal cost of supplying quality (in the sense of an increase in ρ) lowers the power of incentive schemes if quantity and quality are net complements and raises the power of incentive schemes if they are net substitutes.

■ Last, let us consider an increase in k keeping $\frac{h}{k}$ constant. The point of keeping $\frac{h}{k}$ constant is to leave the asymmetry of information unaffected: When facing demand parameter θ, the firm can claim that the demand parameter is $\hat{\theta}$ by choosing services s satisfying $ks-h\theta = ks(\hat{\theta})-h\hat{\theta}$ without being detected through the demand data p and q. Thus the "concealment set" is invariant.

Proposition 5: An increase in k keeping h/k constant raises the power of incentive schemes if quantity and quality are net complements and lowers the power of incentive schemes if they are not substitutes.

Proposition 5 admits several interpretations. First, an increase in k corresponds to an increase in the marginal willingness to pay for the good p if and only if $k > 1$. To see this, note that $\partial p/\partial k = ks-h\theta = (1+\lambda)(k-1)q/k$ from (3.16). Proposition 5 thus says that increases in the marginal willingness to pay for the good tilt the optimal contracts toward a fixed price contract for all k.[13]

Second, $\text{sign}\left[\left.\frac{\partial^2 s^g}{\partial k \partial s}\right|_{\frac{h}{k}=\text{constant}}\right] = \text{sign}\left[1-2(1+\lambda)\left[\frac{k-1}{k}\right]\right]$, (using (3.16)).

Proposition 5 shows that an increase in the marginal valuation for quality $\left[\frac{\partial s^g}{\partial s}\right]$ has an ambiguous effect on the power of incentive schemes: For $k < 1$, an increase in the marginal valuation for quality lowers the power of incentive schemes. For $k > 1$, but "not too large," it raises the power of incentive schemes.

The intuitions for all these propositions are similar. An increase in the concern for quality (or a decrease in the marginal cost of supplying quality) makes higher quality socially desirable. If quality and quantity are net complements, higher quantity is also socially more desirable. Effort becomes then more effective since it affects more units of the product. To encourage effort more powerful incentive schemes are used.

Part B. Experience goods.

6. Reputation incentives.

In some industries the sales incentive is limited because either the quantity purchased is fixed or inelastic, e.g., because it is an experience good or the buyer is the regulator himself, as in the case in procurement, or both. Suppose that the buyer (regulator) buys a fixed amount from the firm.

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[13] This result is similar to the one obtained when unverifiable quality is not an issue (see our [1986] paper).

The firm's main incentive to provide quality is then the threat of jeopardizing future trading opportunities with the buyer rather than current ones. In general terms, one can think of two mechanisms that link current quality and future sales. First, the buyer may develop a reputation for punishing the agent, for instance, by not trading with him, when the latter has supplied low quality in the past. This mechanism is likely to be particularly powerful when the buyer oversees many agents and thus has a good opportunity to develop such a reputation. Second, and closer to the industrial organization tradition, the buyer may infer information about the profitability of future trade from the observation of current quality. We will focus on this second mechanism.

The industrial organization literature has identified two informational reasons why a buyer may find future trade undesirable after observing poor quality. On the one hand, the quality of the product supplied by the seller may have permanent characteristics; that is, the seller commits long-term investments that affect the quality level over several periods. On the other hand, the intertemporal link may be human capital rather than technological investment. The seller then signals his competence or diligence through today's choice of quality and conveys information about tomorrow's future quality even though he will manufacture a possibly brand-new product using new machines. In this section, we focus on a permanent and unverifiable choice of technology. Appendix B develops a model of reputation for being a high quality producer. The two models yield similar results. We will emphasize the new insights added by the new model in the Appendix.

For the seller to care about future trade, it must be the case that this trade creates a rent. This rent can be an informational rent, but other types of rents (due, for instance, to bargaining power of the seller, or to the necessity for the buyer to offer an "efficiency wage" scheme to create incentives) are consistent with the model.

The model has two periods, $\tau = 1,2$. In period 1, the seller (regulated firm) produces one unit of the good for the buyer (regulator), at cost:

$$(6.1) \qquad C_1 = \beta_1 - e_1 + s,$$

where C_1 is the first-period, verifiable cost, β_1 an efficiency parameter, e_1 the firm's effort to reduce the first-period cost, and s the level of "care." As in the sales incentive model of Sections 2 through 5, s is formalized as a monetary cost, but can alternatively be interpreted as a non-monetary cost. The variables β_1, e_1 and s are private information to the firm; the regulator has a prior cumulative distribution $F(\beta_1)$ on $[\underline{\beta}_1,\bar{\beta}_1]$ with density $f(\beta_1)$ that satisfies the monotone "hazard rate" property $\frac{d}{d\beta_1}\left(\frac{F(\beta_1)}{f(\beta_1)}\right) \geq 0$. Effort e_1 involves disutility $\psi(e_1)$ (with $\psi' > 0$, $\psi'' > 0$, $\psi''' \geq 0$). With probability $\pi(s) \in [0,1]$, the product "works" and yields a gross social surplus S_1; with probability $(1-\pi(s))$, the product is defective and yields gross social surplus 0. We will say that the firm produces a high or low quality item respectively. We assume that $\pi' > 0$, $\pi'' < 0$; as well as $\pi'(0) = +\infty$ (in order to avoid a corner solution at $s = 0$) and $\pi''' \leq 0$ (which is a sufficient condition for the regulator's program to be concave). Whether the product works or is defective is observed at the end of period 1 by the regulator, but is not verifiable by a court so that the regulatory contract cannot be contingent on the quality outcome.

Parties have a discount factor $\delta > 0$ between the two periods. To obtain the simplest model, we assume that the firm's second-period product is defective if and only if the first-period product is defective (that is, the first- and second-period quality outcomes are both determined by the first-period level of care and are perfectly correlated. As is easily seen, what matters for the results is that a higher s in period 1 raises the expected quality level in period 2). Our assumption implies that the firm won't be asked to produce in period 2 if its product is defective in period 1;

in this case, the second-period social welfare and firm's rent are normalized to be zero. Let $\bar{U}_2 > 0$ and $\bar{W}_2 > 0$ denote the second-period expected rent for the firm and expected social welfare.[14] For simplicity, we assume that $\bar{U}_2$ and $\bar{W}_2$ are independent of β_1.

Let $\{s(\beta_1), e_1(\beta_1)\}$ denote the firm's first-period care and effort levels functions, and $U_1(\beta_1)$ denote the firm's first-period rent. Note that a firm with type β_1 can always duplicate the cost and probability of high quality of a firm with type $(\beta_1\text{-}d\beta_1)$ by choosing levels $\{s(\beta_1\text{-}d\beta_1), e_1(\beta_1\text{-}d\beta_1)\}$ so that the incentive compatibility constraint for effort is:

$$(6.2) \qquad \dot{U}_1(\beta_1) = -\psi'(e_1(\beta_1)).$$

Next consider the firm's choice of care. Suppose that it raises the level of care by 1. To reach the same cost, the firm must increase its effort by 1. At the margin, such changes do not affect the firm's rent. The incentive compatibility constraint with respect to effort is thus:

$$(6.3) \qquad \delta\pi'(s)\bar{U}_2\text{-}\psi'(e_1) = 0.$$

Next, suppose that the firm cannot produce in period 2 if it hasn't produced (and thus invested) in period 1. The individual rationality constraint says that the firm must obtain at least its reservation utility, which we normalize

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[14]To give an example: suppose that (a) the firm produces one unit of the same good or a related good in period 2 at cost $C_2 = \beta_2\text{-}e_2$, where $\beta_2 \in [\underline{\beta}_2, \bar{\beta}_2]$ is the second-period efficiency parameter, is uncorrelated with β_1 and is learned (by the firm only) between the two periods (β_2 might reflect the new input costs); (b) the second-period gross surplus is equal to S_2 (possibly equal to S_1) if the firm has produced a high quality item in period 1, and zero otherwise; and (c) the regulator offers the second-period contract at the beginning of period 2 (no commitment). In this simple example, $\bar{U}_2$ and $\bar{W}_2$ are computed as in Laffont-Tirole [1986]. Furthermore, if S_2 is sufficiently large relative to $\bar{\beta}_2$, $\bar{U}_2$ is independent of S_2.

at zero: for all β_1:

(6.4) $$U_1(\beta_1)+\delta\bar{U}_2\pi(s(\beta_1)) \geq 0.$$

As is usual, the individual rationality constraint is binding at $\beta_1 = \bar{\beta}_1$ only:[15]

(6.5) $$U_1(\bar{\beta}_1)+\delta\bar{U}_2\pi(s(\bar{\beta}_1)) = 0.$$

Note that type $\bar{\beta}_1$ "buys in"; that is, he is willing to trade a negative first-period rent for an expected second-period rent.[16] Expected social welfare can then be written:

(6.6) $$\int_{\underline{\beta}_1}^{\bar{\beta}_1}[\pi(s)(S_1+\delta\bar{W}_2)-(1+\lambda)(\beta_1-e_1+s+\psi(e_1))-\lambda U_1(\beta_1)]f(\beta_1)d\beta_1.$$

The regulator maximizes (6.6) subject to (6.2), (6.3), and (6.5). Let $\mu(\beta_1)$ and $\nu(\beta_1)f(\beta_1)$ denote the multipliers of constraints (6.2) and (6.3) respectively. The Hamiltonian is:

(6.7) $$\mathcal{H} = [\pi(s)(S_1+\delta\bar{W}_2)-(1+\lambda)(\beta_1-e_1+s+\psi(e_1))-\lambda U_1]f-\mu\psi'(e_1)$$

$$+\nu f[\delta\pi'(s)\bar{U}_2-\psi'(e_1)].$$

We have:

(6.8) $$\dot{\mu} \equiv \frac{d\mu}{d\beta_1} = -\frac{\partial\mathcal{H}}{\partial U_1} = \lambda f.$$

Because $\underline{\beta}_1$ is a free boundary and $F(\underline{\beta}_1) = 0$, we thus obtain

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[15] Indeed it can be checked *ex post* that $\frac{ds}{d\beta_1} < 0$.

[16] Such "buy in" phenomena are typical of non-commitment models, in which firms trade off current losses and future rents. See, e.g., Riordan-Sappington [1988].

$$\mu(\beta_1) = \lambda F(\beta_1). \tag{6.9}$$

Taking the derivatives of $\mathcal{H}$ with respect to the control variables e_1 and s yields:

$$\psi'(e_1) = 1 - \frac{\lambda}{1+\lambda}\frac{F(\beta_1)}{f(\beta_1)}\psi''(e_1) - \frac{\nu}{1+\lambda}\psi''(e_1) \tag{6.10}$$

$$\pi'(s)(S_1+\delta\tilde{W}_2)-(1+\lambda)+\nu\delta\pi''(s)\bar{U}_2 = 0. \tag{6.11}$$

As we will see in the proof of the next proposition, the second-order conditions for maximization are satisfied. The solution $(e_1(\beta_1), s(\beta_1), \nu(\beta_1))$ is thus given by (6.3), (6.10), and (6.11). We now derive the comparative statics results using the interpretation of the optimal incentive scheme as a menu of linear contracts (see Appendix A.7).

Proposition 6: Optimal cost reimbursement rules are linear. The first-period contract tends toward a cost-plus contract (the slope of the incentive scheme decreases for all β_1) when

a) the discount factor δ decreases;

b) (if $\frac{\partial \tilde{W}_2}{\partial S_1} \geq 0$ and $\frac{\partial \bar{U}_2}{\partial S_1} = 0$. See footnote 14 for an example) the social value of quality S_1 increases.

Proof: See Appendix A.8.

Thus, when quality becomes very important, the firm must be given a low-powered incentive scheme to supply more care (result b)). This illustrates the crowding-out effect, according to which care and effort are substitutes, so that the production of more quality is obtained at the expense of cost-reducing activities. Last, result a) formalizes the reputation

argument. Far-sighted firms can be given high-powered incentive schemes.

7. Concluding remarks.

We have analyzed the circumstances under which quality concerns call for low-powered incentive schemes. For an experience good, the lack of informational value of the current sale indicator makes the cost reimbursement rule the only instrument to achieve the conflicting goals of provision of quality and cost reduction. A high concern for quality leads to low-powered incentive schemes. We have also argued that steeper incentive schemes are optimal if the supplier is sufficiently eager to preserve his reputation. For a search good, there is no "crowding-out effect" as direct sales incentives can be provided. There is, however, a new, "scale effect" of quality concern on the power of incentive schemes; a high concern for quality leads to low-powered incentive schemes if and only if quantity and quality are net substitutes.

The paper has considered the important polar cases of a search good with scale effects (in which a higher output makes cost reduction more valuable) and of an experience good without scale effect (for which ouput was taken as given). Understanding the crowding-out and the scale effects makes it easy to extend the theory to cover the other two polar cases. Consider first a search good and assume that the cost-reducing activity affects the fixed cost rather than the marginal cost: $C = cq+\beta-e+s$.[17] When quality becomes more desirable, output changes,[18] but the optimal effort is unaffected. Because direct sales incentives can be given and because there is no scale effect, the power of

[17] This technology is chosen so as to keep the adverse selection one-dimensional and as to yield a closed-form solution. The analysis, which follows the lines of Section 3 is left to the reader.

[18] For the above cost function, output increases, as the goods are net complements as long as they are gross complements.

incentive schemes is independent of the demand for quality. Second, consider an experience good with variable scale such that a) a higher quality raises the demand for the good and b) the effort reduces the marginal cost. For such a good, a higher valuation for quality raises demand for the good and creates a scale effect that may offset the crowding-out effect. Thus we have:

	Search Good	Experience Good
Effort reduces marginal cost	+ is q and s net complements − if q and s net substitutes	Ambiguous
Effort reduces fixed cost	0	−

Table 1: Effect of an increase in the demand for quality on the power of incentive schemes.

We should also note that scale effects can take other forms than the one obtained in this paper. If the two moral hazard variables s and e interact in the cost function ($\partial^2 C/\partial s \partial e \neq 0$), an increase in the demand for quality has a direct effect on effort, not only an indirect one through the complementarity or substitutability of quality and output. While ruling out this interaction is a good working hypothesis, one can think of situations in which effort produces a new technology that reduces the marginal cost of providing services ($\partial^2 C/\partial s \partial e < 0$). We conjecture that in such situations, there is a new scale effect, that leads to high-powered incentive schemes when the demand for quality is high.

Our theory may also shed some light on the behavior of more complex regulatory hierarchies, for instance ones in which regulators have other objectives than maximizing welfare. For instance, suppose that the regulator

derives perks from the supplier's delivering high-quality products. That is, the regulator values quality more than the public at large. The regulator will then lobby in favor of low-powered incentive schemes if the good is an experience good. Our theory thus offers a clue as to why Department of Defense officials who value quality highly sometimes manage to transform fixed-price contracts into cost-plus contracts.[19]

Last, the distinction between verifiable and unverifiable quality is extreme. More generally one would want to allow quality to be verifiable at a cost. It would be worthwhile to analyze the relationship between expenses to monitor quality, quality and reputation concerns and power of incentive schemes.

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[19] See also Scherer [1964, pp. 33-34 and 236-239]. DoD officials are well-known to favor performance over cost. They often feel that fixed-price contracts encourage contractors to make "uneconomic" reliability tradeoffs and make them reluctant to make design improvements.

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APPENDIX A.1.

Let $\gamma = \beta + \frac{h}{k}\theta$ and assume for notational simplicity that $h = k$. It is reasonable in this problem to assume that the distributions of β and θ, $F_1(\cdot)$ and $F_2(\cdot)$ are independent. Then

$$F(\gamma) \equiv \text{Prob}(\tilde{\gamma} \leq \gamma) = \int_{-\infty}^{+\infty} \text{Prob}(\theta \leq \tilde{\theta} \leq \theta + d\theta)\text{Prob}(\beta \leq \gamma - \theta)$$

$$= \int_{-\infty}^{+\infty} f_2(\theta)F_1(\gamma-\theta)d\theta,$$

$$f(\gamma) = \int_{-\infty}^{+\infty} f_2(\theta)f_1(\gamma-\theta)d\theta,$$

and

$$\frac{d}{d\gamma}\left[\frac{F(\gamma)}{f(\gamma)}\right] = 1 - \frac{\int_{-\infty}^{+\infty} f_2(\theta)F_1(\gamma-\theta)d\theta \int_{-\infty}^{+\infty} f_2(\theta)f_1'(\gamma-\theta)d\theta}{\left(\int_{-\infty}^{+\infty} f_2(\theta)f_1(\gamma-\theta)d\theta\right)^2} .$$

In particular, if β is uniformly distributed (or, by symmetry if θ is uniformly distributed), $\frac{d}{d\gamma}\left[\frac{F(\gamma)}{f(\gamma)}\right] = 1 > 0$.

More generally, if one of the densities is non increasing ($f_1' \leq 0$ or $f_2' \leq 0$), $F(\cdot)$ satisfies the monotone hazard-rate condition.

§ § §

APPENDIX A.2.

The firm is faced with the revelation mechanism $t(\tilde{\gamma})$, $p(\tilde{\gamma})$, $q(\tilde{\gamma})$, $\left[\frac{C}{q}\right](\tilde{\gamma})$. For simplicity we assume that the mechanism is differentiable (see Guesnerie and Laffont [1984] for a proof of this). The firm chooses the announcement $\tilde{\gamma}$ which maximizes its objective function, i.e., solves:

(A2.1) $$\underset{\tilde{\gamma}}{\text{Max}}\left\{t(\tilde{\gamma})-\psi(\gamma+\frac{p(\tilde{\gamma})-A+Bq(\tilde{\gamma})}{k}-\frac{C}{q}(\tilde{\gamma}))\right\}$$

$$\Leftrightarrow \underset{\tilde{\gamma}}{\text{Max}}\left\{t(\tilde{\gamma})-\psi(\gamma-z(\tilde{\gamma}))\right\},$$

where

$$z(\tilde{\gamma}) = \frac{C}{q}(\tilde{\gamma}) - \frac{p(\tilde{\gamma})-A+Bq(\tilde{\gamma})}{k}.$$

The first-order condition of incentive compatibility is:

(A2.2) $$\dot{t}(\gamma)+\psi'(\gamma-z(\gamma))\dot{z}(\gamma) = 0,$$

and the second-order condition is

(A2.3) $$\dot{z}(\gamma) \geq 0.$$

(A2.2) and (A2.3) constitute necessary and sufficient conditions for incentive compatibility (see Guesnerie-Laffont [1984]).

Note that $z(\gamma) = \gamma-e(\gamma)$. So the second-order condition can be rewritten:

(A2.4) $$\dot{e}-1 \leq 0.$$

§ § §

APPENDIX A.3.

The regulator maximizes H with respect to $\{q,p,e\}$. The matrix of second-derivatives of H with respect to these variables is (divided by f):

$$\begin{bmatrix} B-B^2-\frac{2(1+\lambda)B}{k} & (1+\lambda)-B-\frac{(1+\lambda)}{k} & 1+\lambda \\ (1+\lambda)-B-\frac{(1+\lambda)}{k} & -1 & 0 \\ 1+\lambda & 0 & -(1+\lambda)\psi''-\frac{\lambda F\psi'''}{f} \end{bmatrix}$$

[This matrix differs from the Jacobian of equations (3.15) through (3.17) in that (3.16) was used to obtain equation (3.15).] For the sub-matrix in (q,p) to be semi-definite negative it must be the case that

$$\text{(A3.1)} \qquad B > 1 - \frac{2(1+\lambda)}{k}$$

and

$$\text{(A3.2)} \qquad B(1+2\lambda) > (1+\lambda)^2\left(1 - \frac{1}{k}\right)^2.$$

The determinant is:

$$\Delta = -(1+\lambda)q\Delta_1+(1+\lambda)^2,$$

where Δ_1 is the determinant of the submatrix in (q,p). Or:

$$\Delta < 0 \iff q\Delta_1 > 1+\lambda.$$

Solving (3.15) and (3.16), we get:

$$\Delta_1 q = (1+\lambda)(A-(\gamma-e)).$$

To sum up, sufficient conditions for the second-order conditions to be satisfied are:

$$A > \gamma+1$$

$$B > \mathrm{Max}\left\{1 - \frac{2(1+\lambda)}{k}, \frac{(1+\lambda)^2}{1+2\lambda}\left(1 - \frac{1}{k}\right)^2\right\}.$$

Moreover, the solution obtained in Section 3 is valid if the second-order incentive constraint $\dot{e} \leq 1$ is satisfied by the solution of the above first-order equations.

Differentiating (3.15), (3.16) and (3.17), we obtain:

$$\text{(A3.3)} \qquad -\left(\lambda + \frac{(1+\lambda)}{k}\right)B\dot{q}+(1+\lambda)\left(1 - \frac{1}{k}\right)\dot{p} + (1+\lambda)\dot{e} = 1+\lambda$$

(A3.4) $\quad ((1+\lambda)(k-1)-Bk)\dot{q}-k\dot{p} = 0$

(A3.5) $\quad \dot{q} - \left[\psi''(e) + \frac{\lambda}{1+\lambda}\frac{F(\gamma)}{f(\gamma)}\psi'''(e)\right]\dot{e} = \frac{\lambda}{1+\lambda}\psi''(e)\,\frac{d}{d\gamma}\left[\frac{F(\gamma)}{f(\gamma)}\right].$

Hence,

$$\dot{p} = \frac{1}{\Delta}\left[(1+\lambda)(k-1)-Bk\right](1+\lambda)\left[\psi''(e) + \frac{1}{1+\lambda}\frac{F(\gamma)}{f(\gamma)}\psi'''(e) + \frac{\lambda}{1+\lambda}\psi''(e)\,\frac{d}{d\gamma}\left[\frac{F(\gamma)}{f(\gamma)}\right]\right],$$

where Δ is the determinant of the system which is negative since we are at a maximum. Since $\psi'' > 0$, $\psi''' \geq 0$ and $\frac{d}{d\gamma}\left[\frac{F(\gamma)}{f(\gamma)}\right] > 0$, $\dot{p} > 0$ for $B > \frac{(1+\lambda)(k-1)}{k}$ which, if $B > 1$, is automatically satisfied in the relevant range: (3.16) implies that $\frac{\partial S^g}{\partial s} = kq(1-(1+\lambda)(1 - \frac{1}{k})) > 0$. From (A3.4), $\dot{q} < 0$ and $\dot{e} < 0$ from (A3.5). In that case, the second-order condition of incentive compatibility is satisfied.

§ § §

Appendix A.4.

The dichotomy result between optimal pricing and quality and optimal incentive schemes obtained in Section 3 can be generalized as follows:

Let $\tilde{C}(\beta,e,q,s)$ denote a general cost function and let $s = \xi(\theta,q,p)$ be obtained by inverting the demand function $q = D(p,s,\theta)$.

The derived cost function is:

$$C(\beta,\theta,e,q,p) = \tilde{C}(\beta,e,q,\xi(\theta,q,p)).$$

Let $e = E(\beta,\theta,C,q,p)$ be the solution of

$$C(\beta,\theta,e,q,p) = C.$$

The problem is here genuinely two-dimensional. The first-order incentive constraints can be written:

$$U_\beta = -\psi'(e)E_\beta,$$

$$U_\theta = -\psi'(e)E_\theta,$$

$$U_{\beta\theta} = U_{\theta\beta},$$

where subscripts denote partial derivatives.

A sufficient condition for the dichotomy result is[20]

$$\frac{\partial E_\beta}{\partial q} = \frac{\partial E_\beta}{\partial p} = \frac{\partial E_\theta}{\partial q} = \frac{\partial E_\theta}{\partial p} = 0,$$

which requires (from Leontieff's theorem) that there exists $\Lambda(\cdot,\cdot)$, $\Gamma(\cdot,\cdot)$ such that

$$C = C(\Lambda(\beta,e),\Gamma(\theta,e),p,q),$$

a special case of which is

$$C = C(\Phi(\beta,\theta,e),p,q).$$

In our example, we have $\Phi(\beta,\theta,e) = \beta + \frac{h\theta}{k} - e$.

§ § §

Appendix A.5.

Since the equations defining quality and price are the same as under complete information (dichotomy result) the comparison between complete and incomplete information can be easily obtained by observing that incomplete information gives a lower level of effort conditionally on the level of

[20] If these conditions hold, the derivatives of the Hamiltonian with respect to p and q involve no terms associated with the incentive constraints and therefore with asymmetric information.

production (equation (3.17)). This decrease of effort itself leads, from (3.15) and (3.16) to a decrease of q (reinforcing the initial decrease of effort which is therefore an unconditional decrease of effort) and to an increase in p.

For any γ let us call (de) an infinitesimal decrease in effort. Differentiating (3.15) and (3.16) yields:

$$k\frac{ds}{de} = \frac{dp}{de} + B\frac{dq}{de} = (1+\lambda)\left(1 - \frac{1}{k}\right) \frac{dq}{de}.$$

The conclusion follows from the fact that e and q are lower under incomplete information from the first- and second-order conditions.

§ § §

Appendix A.6.

<u>Proof of Propositions 3, 4, and 5.</u>

We offer a single proof to the three propositions. After substituting for the shadow price of (3.10) (see (3.14)), the Hamiltonian becomes:

$$\text{(A6.1)} \qquad H = \frac{B}{2}q^2+(1+\lambda)pq - \frac{1}{2}(p-A+Bq)^2+\ell(p-A+Bq,\nu)$$
$$- (1+\lambda)\left[(\gamma-e)q+q\left[\frac{p-A+Bq}{k}\right]+m(p-A+Bq,\rho)+\psi(e)\right]$$
$$- \lambda \frac{F}{f}\psi'(e).$$

Letting $\Delta < 0$ denote the determinant of the Jacobian with respect to the control variables (q,p,e), we have

$$\text{(A6.2)} \qquad \frac{de}{dx} = -\frac{1}{\Delta} \begin{vmatrix} \frac{\partial^2 H}{\partial q^2} & \frac{\partial^2 H}{\partial q \partial p} & \frac{\partial^2 H}{\partial q \partial x} \\ \frac{\partial^2 H}{\partial q \partial p} & \frac{\partial^2 H}{\partial p^2} & \frac{\partial^2 H}{\partial p \partial x} \\ \frac{\partial^2 H}{\partial e \partial q} & \frac{\partial^2 H}{\partial e \partial p} & \frac{\partial^2 H}{\partial e \partial x} \end{vmatrix}$$

for $x = \nu, \rho, k$.

But $\frac{\partial^2 H}{\partial e \partial q} = (1+\lambda)$, $\frac{\partial^2 H}{\partial e \partial p} = 0$ and $\frac{\partial^2 H}{\partial e \partial x} = 0$ for $x = \nu, \rho, k$. Hence,

$$\text{(A6.3)} \qquad \text{sign}\left(\frac{de}{dx}\right) = \text{sign} \begin{vmatrix} \frac{\partial^2 H}{\partial q \partial p} & \frac{\partial^2 H}{\partial q \partial x} \\ \frac{\partial^2 H}{\partial p^2} & \frac{\partial^2 H}{\partial p \partial x} \end{vmatrix}.$$

The propositions follow from:

$$\frac{\partial^2 H}{\partial q \partial p} = (1+\lambda)\left(1 - \frac{1}{k}\right) - B(1+m_{11}(1+\lambda)-\ell_{11})$$

$$\frac{\partial^2 H}{\partial p^2} = -(1+m_{11}(1+\lambda)-\ell_{11})$$

$$\frac{\partial^2 H}{\partial q \partial \nu} = B\ell_{12} = B\,\frac{\partial^2 H}{\partial p \partial \nu}\ ; \quad \frac{\partial^2 H}{\partial q \partial \rho} = -Bm_{12} = B\,\frac{\partial^2 H}{\partial p \partial \rho};$$

$$\frac{\partial^2 H}{\partial q \partial k} = \frac{1+\lambda}{k^2}(p-A+2Bq)\ ; \quad \frac{\partial^2 H}{\partial p \partial k} = \frac{1+\lambda}{k^2}q.$$

[To obtain Proposition 5, use (3.16) to substitute (p-A+Bq)].

§ § §

Appendix A.7: The linearity of contracts.

From Laffont-Tirole [1986] we know that we can decentralize a non-linear contract with a menu of linear contracts if the transfer $t(C_1)$ is convex. From the first-order conditions of incentive compatibility

$$\frac{dt}{d\beta_1} + \psi'(e_1)\frac{dC_1}{d\beta_1} = 0 \qquad \text{with} \qquad \frac{dC_1}{d\beta_1} \geq 0$$

from second-order incentive compatibility conditions. Hence

$$\frac{dt}{dC_1} = -\psi'(e_1) \qquad \text{and} \qquad \frac{d^2t}{dC_1^2} = -\psi''\dot{e}_1 \frac{1}{\frac{dC_1}{d\beta_1}}$$

$t(C_1)$ is convex iff $\dot{e}_1 < 0$. Differentiating the first-order conditions we get:

$$\dot{e}_1 = -(\delta\pi''\bar{U}_2)^2 \frac{\lambda}{1+\lambda}\psi'' \frac{d}{d\beta_1}\frac{F(\beta_1)}{f(\beta_1)} \Bigg/ \Bigg[(\delta\pi''\bar{U}_2)^2\left[(1+\lambda)\psi''+\lambda\frac{F(\beta_1)}{f(\beta_1)}\psi'''+\nu\psi'''\right]$$

$$-((S_1+\delta\bar{W}_2)(\pi''+\nu\delta\pi'''\bar{U}_2)(\psi'')^2\Bigg]$$

$$< 0.$$

§ § §

APPENDIX A.8.

<u>Proof</u> <u>of</u> <u>Proposition</u> <u>6</u>: Differentiating (6.10), (6.11), and (6.3) totally yields

(A8.1) $$\left[\psi''+\left(\frac{\lambda}{1+\lambda}\frac{F}{f}+\frac{\nu}{1+\lambda}\right)\psi'''\right]de_1 = -\frac{\psi''}{1+\lambda}d\nu.$$

(A8.2) $$\left[\pi''(S_1+\delta\bar{W}_2)+\nu\delta\bar{U}_2\pi'''\right]ds+\left[\pi'+\delta\frac{\partial\bar{W}_2}{\partial S_1}\right]dS_1$$

$$+\ [\nu\pi''\bar{U}_2+\pi'\bar{W}_2]d\delta+\delta\pi''\bar{U}_2d\nu = 0.$$

(A8.3) $$\psi''de_1 = (\pi'\bar{U}_2)d\delta+(\delta\bar{U}_2\pi'')ds.$$

Substituting:

(A8.4) $$\text{sign}\left(\frac{\partial e_1}{\partial S_1}\right) = \text{sign}\left(-\left[\pi'+\delta\frac{\partial\bar{W}_2}{\partial S_1}\right]\right) < 0$$

(A8.5) $$\text{sign}\left(\frac{\partial e_1}{\partial \delta}\right) = \text{sign}(-\pi''\pi'\bar{U}_2S_1-\delta\nu\bar{U}_2^2\pi'''\pi'+\delta\bar{U}_2^2(\pi'')^2\nu) > 0.$$

using (6.11), $\psi''' \geq 0$ and $\pi''' \leq 0$. Furthermore, it is easily seen that the assumptions $\psi''' \geq 0$ and $\pi''' \leq 0$ guarantee that the second-order conditions are satisfied.

§ § §

Appendix B: Quality, asymmetric information and reputation.

We consider a two-period model in which the firm is, with probability x, a high-quality producer, i.e., generates a social surplus S^H when producing. With probability $1-x$ it is a low-quality producer, i.e., generates a social surplus $S^L < S^H$, unless it puts some effort $s > 0$, in which case the social surplus is S^H.

To avoid signaling issues which would complicate the analysis, we assume that the firm does not know in period 1 if it is a high or a low-quality producer. (Thus the model is closer to Holmström [1982]'s than to Kreps-Wilson [1982]'s and Milgrom-Roberts [1982]'s). Moreover, quality cannot be contracted upon. At the end of period 1, if production occurs, the regulator discovers the quality level.

In period 1, the firm has a cost function

$$C_1 = \beta_1 - e,$$

where β_1 is known to and C_1 observed by the regulator, and e_1 is a cost-reducing effort. Total effort for the firm is $e_1 = e$ or $e_1 = e+s$ when the firm is putting the extra effort s to make sure that first-period quality is high. Let t_1 be the transfer given to the firm in period 1.

The regulator cannot commit for period 2. In period 2 the firm has a cost parameter $\beta_2 \in [\underline{\beta},\bar{\beta}]$ with a (common knowledge) distribution $F(\cdot)$ and a cost function:

$$C_2 = \beta_2 - e_2.$$

β_2 will be learned by the firm at the beginning of date 2. Therefore at that time we will be in a one-period adverse-selection problem (Laffont-Tirole [1986]).

For any expected social surplus S in period 2, second-period welfare is:

$$W^*(S) = \int_{\underline{\beta}}^{\bar{\beta}} \left\{ S - (1+\lambda)(\psi(e^*(\beta_2)) + \beta_2 - e^*(\beta_2)) - \lambda U^*(\beta_2) \right\} dF(\beta_2),$$

where (according to Laffont-Tirole [1986])

$$\psi'(e^*(\beta_2)) = 1 - \frac{\lambda}{1+\lambda} \frac{F(\beta_2)}{f(\beta_2)} \psi''(e^*(\beta_2))$$

$$U^*(\beta_2) = - \int_{\beta_2}^{\bar{\beta}} \psi'(e^*(\tilde{\beta}_2)) d\tilde{\beta}_2.$$

Let t^*, C^*, U^* be the expected transfer, cost and rent in this optimal second-period mechanism.

To limit the analysis to the most interesting cases, we postulate

Assumption 1: If $S = xS^H+(1-x)S^L$, $W^*(S) > 0$ for any $F(\cdot)$ on $[\underline{\beta},\bar{\beta}]$.

If $S = S^L$, $W^*(S) < 0$ for any $F(\cdot)$ on $[\underline{\beta},\bar{\beta}]$.

Assumption 1 means that for an expected quality defined by the prior, it is worth realizing the project. However, if the firm is known to be a low-quality firm, it is not worth doing it, even if attention is restricted to the best types (close to $\underline{\beta}$). Assumption 1 requires that $(\bar{\beta}-\underline{\beta})$ not be "too large."

Assumption 2: $s < \frac{(1-\delta)(1-x)}{1+\lambda} (S^H-S^L)$.

Assumption 2 means that the extra effort needed to upgrade quality is not too high compared to the social gain (S^H-S^L). Without this assumption, it is never optimal to induce upgrading of quality in the first period.

Two policies must be considered. In policy A, s is not induced, and in policy B, s is induced (inducing randomization by the firm is never optimal).

Policy A:

Social welfare is

$$W = xS^H+(1-x)S^L-(1+\lambda)(\beta_1-e_1+t_1)+\delta x(S^H-(1+\lambda)(t^*+C^*))+U,$$

where U is the firm's intertemporal rent, and we use the fact that in period 2 the regulator knows whether he is facing a high-quality firm.

Social welfare must be maximized under the individual rationality (IR) and incentive compatibility (IC) constraints.

If the firm does not produce in period 1, the regulator learns nothing and the firm can expect a rent U^* in period 2. Accordingly, the IR-constraint takes the form

$$(IR_A) \qquad t_1-\psi(e_1)+\delta xU^* \geq \delta U^*.$$

The IC constraint is

$$(IC_A) \qquad t_1-\psi(e_1)+\delta xU^* \geq t_1-\psi(e_1+s)+\delta U^*.$$

In regime I, (IC_A) is not binding and therefore

$$\psi'(e_1) = 1 \text{ or } e_1 = e^*$$

$$t_1 = \psi(e_1)+\delta(1-x)U^*$$

$$U = \delta U^*.$$

(IC_A) can be rewritten with $\tilde{\Phi}(e) \equiv \psi(e+s)-\psi(e)$,

$$\tilde{\Phi}(e_1) \geq \delta(1-x)U^* \text{ or } \delta \leq \delta_1,$$

where $\tilde{\Phi}(e^*) \equiv \delta_1(1-x)U^*$.

In regime II, (IC_A) is binding, and effort is defined by

$$\tilde{\Phi}(e(\delta)) = \delta(1-x)U^*,$$

with $\frac{de}{d\delta} > 0$ and $e(\delta) > e^*$. Welfare is then

$$W^I = xS^H+(1-x)S^L-(1+\lambda)(\beta_1-e^*+\psi(e^*))+\delta xW^*(S^H)-\lambda(1-x)\delta U^*$$

$$W^{II} = xS^H+(1-x)S^L-(1+\lambda)(\beta_1-e^*(\delta)+\psi(e^*(\delta)))+\delta xW^*(S^H)-\lambda(1-x)\delta U^*.$$

$W^I \geq W^{II}$, but regime I is not feasible for $\delta > \delta_1$.

Policy B:

Social welfare is now:

$$W = S^H-(1+\lambda)(\beta_1-(e_1-s)+t_1)+\delta\left[S^H-(1-x)(S^H-S^L)-(1+\lambda)(t^*+C^*)\right]+U$$

with the constraints

$$(IR_B) \qquad t_1-\psi(e_1)+\delta U^* \geq \delta U^*$$

$$(IC_B) \qquad t_1-\psi(e_1)+\delta U^* \geq t_1-\psi(e_1-s)+\delta xU^*.$$

In regime III, (IC_B) is not binding, and $e_1 = e^*$, $t_1 = \psi(e_1)$.

Regime III prevails as long as

$$\tilde{\Phi}(e_1-s) = \psi(e_1)-\psi(e_1-s) \leq \delta(1-x)U^*$$

or $\delta > \delta_0$ with $\delta_1 > \delta_0$.

If $\delta < \delta_0$, (IC_B) is binding and e_1 is defined by

$$\tilde{\Phi}(e_1-s) = \delta(1-x)U^*$$

or $e_1 = e(\delta)+s$ with $s+e(\delta) < e^*$ (regime IV).

For $\delta \leq \underline{\delta}$ defined by $s = e(\underline{\delta})$, it is <u>not possible</u> to induce quality.

Welfares are

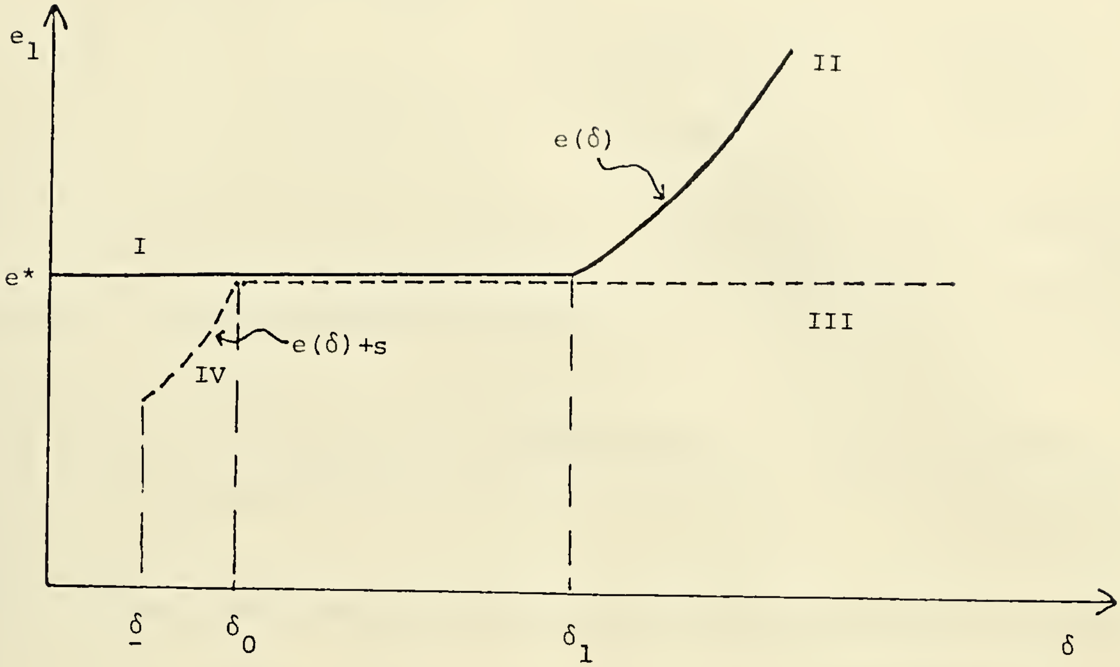
$$W^{III} = S^H-(1+\lambda)(\beta_1-e^*+s+\psi(e^*))+\delta(W^*(S^H)-(1-x)(S^H-S^L))$$

$$W^{IV} = S^H-(1+\lambda)(\beta_1-e(\delta)+\psi(e(\delta)+s))+\delta(W^*(S^H)-(1-x)(S^H-S^L)).$$

Effort levels are summarized in Figure 2:

FIGURE 2 HERE

<u>Lemma 1</u>: $W^{III} > W^I$.



e_1
II
$e(\delta)$
I
e^*
III
$e(\delta)+s$
IV
$\underline{\delta}$
δ_0
δ_1
δ

FIGURE 2

Proof:

$$W^{III}-W^{I} = (1-\delta)(1-x)(S^H-S^L)-(1+\lambda)s$$
$$+ (1-x)\delta(S^H-(1+\lambda)E(\psi(e^*(\beta_2)+\beta_2-e^*(\beta_2))).$$

The sum of the first two terms is positive in view of A.2 and the third term is positive in view of A.1.

Q.E.D.

As $W^{II} < W^{I}$, regime III is optimal for $\delta \geq \delta_0$. For $\delta < \underset{\bar{}}{\delta}$, regime I is clearly optimal.

Lemma 2: a) There exists $\hat{\delta} \in [\underline{\delta}, \delta_0)$ such that for $\delta > \hat{\delta}$ the optimum is to induce quality and

$$e_1 = e(\delta)+s < e^* \quad \text{if } \hat{\delta} < \delta \leq \delta_0$$
$$= e^* \quad \text{if } \delta > \delta_0.$$

b) If $S^H-S^L < \lambda U^*$, for $\delta < \hat{\delta}$ the optimum is not to induce quality and $e_1 = e^*$.

Proof: a) At $\delta = \delta_0$, $W^{III} = W^{IV}$. Apply Lemma 1.

b) $$\frac{dW^I}{d\delta} = xW^*(S^H)-\lambda(1-x)U^*$$

$$\frac{dW^{IV}}{d\delta} = W^*(S^H)-(1-x)(S^H-S^L)-(1+\lambda)(\psi'(e(\delta)+s)-1)\frac{de}{d\delta}$$

and

$$\frac{de}{d\delta} = \frac{(1-x)U^*}{\psi(e(\delta)+s)-\psi'(e(\delta))}$$

$$\frac{dW^{IV}}{d\delta} = W^*(S^H)+\frac{(1+\lambda)(1-x)U^*(1-\psi'(e(\delta)+s))}{\psi'(e(\delta)+s)-\psi'(e(\delta))} - (1-x)(S^H-S^L).$$

If $s^H - s^L < \lambda U^*$, $\frac{dW^{IV}}{d\delta} > \frac{dW^I}{d\delta}$, hence the result.

Q.E.D.

Thus, we get:

<u>Proposition 7</u>: a) Incentives are higher when one does not want to induce quality.

b) Conditional on inducing quality, the incentive scheme becomes more high-powered when δ increases.

<u>Proof</u>: a) follows from the fact that $e_1 \leq e^*$ when quality is induced.

b) follows from $\frac{de}{d\delta} > 0$.

Q.E.D.

The results are thus very similar to those of the moral hazard model of Section 6. A difference is that incentives are no monotonic in the discount factor. For a low discount factor, an extremely low-powered incentive scheme is needed for the firm to exert s. The loss of incentive to reduce cost is too costly, which yields a corner solution: Because the firm is not induced to provide quality and β_1 is common knowledge, the first-period contract is a fixed-price contract. But as long as the discount factor is sufficiently high to make it worthwhile to induce quality, incentives to reduce cost increase with the discount factor.